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METRIC

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INTRODUCTION TO METRICS

WHY METRIC ??????

1. HISTORICAL BACKGROUND

Developed at the time of the French Revolution, the metric system rapidly spread throughout Europe during the Napoleonic wars. It was promoted in the United States first by Thomas Jefferson and later by John Quincy Adams, but the Federal Government took no formal action on metric measurement until 1866 when its use as a measurement system was legalized. In 1893, all standard U.S. measures were defined in terms of metric units. In 1902, Congressional legislation requiring the Federal Government to use metric exclusively was defeated by a single vote. Today, the United States is the last industrialized country to convert to the metric system. The term "SI" is an abbreviation for International System of Units. It is a modern-day metric system and was established by international agreement in 1960. It now provides a standard international language to describe measurement.

2. LEGAL BASIS FOR HIGHWAY CONVERSION

Metric Conversion Act of 1975 & Omnibus Trade and Competitiveness Act of 1988

The impetus for the change came from Congress. *The Metric Conversion Act of 1975* encouraged metrication, but left it as a voluntary activity. As a consequence, virtually no metrication took place. The *Omnibus Trade and Competitiveness Act of 1988* amended the 1975 Act to designate the modern metric system (System International or SI) as the preferred system of weights and measures for U.S. trade and commerce. It also requires each federal agency to convert to metric, and requires each federal agency to use metric in its procurements, grants, and other business-related activities to the extent economically feasible.

These acts did not mandate that individual states, cities, counties, industries, or other organizations convert to metric. However, these entities cannot obtain federal roadway money unless they use metric. It is probable that all will convert to metric to remain eligible for road funds, and it is best that we all convert quickly using consensus guidelines.

Executive Order 12770

In addition to the congressional legislation, Executive Order 12770 was issued in July 1991. It required each federal agency to adopt a metric conversion plan by November 30, 1991. Among the other provisions of the executive order were instructions that the Department of Commerce was to lead the metrication effort.

The Federal Highway Administration Metric Transition Plan was approved by the Secretary of Transportation in October 1991. It laid out procedures and administrative policies for the conversion, and established certain milestone dates. For example, after September 30, 1992, FHWA publications and correspondence were to use metric as the primary system of units for all measurements. FHWA manuals and documents were to be systematically revised and republished in metric so they would be available to guide the conversion. The key date is September 30, 1996. All construction advertised for bids after that date must contain only metric measurements for any federal lands highway or federal-aid highway construction project.

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U.S. DOT Metric Conversion Planning Guidelines

On May 8, 1990, the U.S. Department of Transportation (U.S. DOT) issued Order 1020.1C which established policy and administrative procedures for the transition. A change to the order was published in January of 1991. It was further amended and issued as Order 1020.1D on March 23, 1992. The Order defines SI as the official metric system, and refers to ASTM E 380 and several other industry standards and documents for guidance on conversion from U.S. units to SI.

The U.S. DOT order requires agencies to develop plans for conversion to SI to the extent practical. These plans are to include specific dates for changeover to SI in procurements, grants and other business-related activities. U.S. DOT is to participate in the Interagency Committee on Metric Policy, and a U.S. DOT Metric Coordination Committee was created. The Order also contains guidance to U.S. DOT agencies to assist them in completing their conversion plans.

The U.S. DOT Metric Coordinator indicated in early 1992, "It is now the policy of the department to pursue and promote an orderly changeover to the SI system." He also noted that there were nine comprehensive metric conversion plans in place for the nine U.S. DOT agencies, including the Federal Highway Administration (FHWA).

3. MOTIVATION FOR METRICS

BENEFITS OF METRIC CONVERSION

International Acceptance

Metric is the world's measurement language. Fewer and fewer cultures are familiar with U.S. measurement units, and many are increasingly unwilling to overcome this hurdle in order to purchase and utilize American goods. The costs associated with doing business in this country (labor, taxes, tariffs, etc.) make it difficult for U.S. firms to produce their goods at prices which are attractive to other nations. They do not need the additional handicaps of non-standard sizes and a measurement system which is the exception rather than the rule.

International Competitiveness

Greater industrial efficiency and international competitiveness are available through the metric system. Canada has already converted to metric. The Canadian Metric Association reported that the metric system produced direct benefits in terms of reduction in design costs and times, increased construction efficiencies, and improved material and component dimensioning techniques.

Private Sector Conversions Already Underway

Some U.S. businesses have already converted. One of the earliest industries to be affected by metrics was the automobile manufacturing sector. General Motors made an early decision that it must convert its manufacturing. Surprisingly, total conversion costs for GM were less than 1% of their original estimates. IBM and Otis Elevator are other examples of firms that have switched to metric, in this case to increase international competitiveness and to reduce their parts inventories. The wood industry has converted to metric for international sales. Timber products are being shipped overseas in metric sizes.

NECESSITY FOR CONVERSION

As of 1990, there were only three nations that had not converted to metric: Burma, Liberia, and the United States. Subsequently, these three nations face serious difficulties in exchanging information with other nations in performing engineering or construction work with other countries.

The current global economy presents serious difficulty. At the end of World War II, the United States was the center of world commerce. At that time, America produced 75% of the world's products; today that value has shrunk to 25%. The world economy has changed rapidly, and industry in the United States is being placed at an increasing disadvantage because of its non-metric system of measurements. American firms are sometimes excluded from doing international business when unable to measure goods in metric terms. A few facts will help put this into perspective:

- The European Community (EC) is composed of 12 nations and is potentially the world's most powerful market, surpassing the United States. The EC specified that products with non-metric labels will not be permitted for sale after 1992.
- The largest U.S. trading partners, Canada and Mexico, are predominantly metric countries.
- Japan has identified the non-metric nature of U.S. products as a specific barrier to the importation of U.S. goods.

Opportunity to Consolidate or Redesign

The conversion process allows industries an opportunity to rethink their designs and to incorporate efficient practices. One way to do this is to designate fewer product sizes, reducing inventories and eliminating some manufacturing equipment. Rationalization of fastener sizes during metric conversion allowed IBM to reduce its number of fasteners from 30,000 to 4,000. The liquor industry reduced the number of container sizes from 53 to 7 during its metric conversion.

International Market for Engineering Services

Many American design and construction firms have already begun using metric units for their foreign work. Foreign billings for American architecture/engineering contracting firms amounted to $3.2 billion in 1989, a substantial amount of business.

Simplicity

Perhaps the strongest argument in favor of the metric system is its simplicity of use. It is completely decimal based. There is no need to convert from one type of measurement to another type of measurement. For example, inches do not have to be converted to feet. Feet do not have to be converted to miles. Tablespoons do not have to be converted to cups. There is no requirement to change 27 feet, 8¼ inches into the equivalent number of yards.

The universal experience of every country that has converted has been that the metric system was easier to learn and easier to use than the convoluted system currently being used in the United States. It is just getting the transition underway that is hard. Once the mental leap has been made, calculations are much, much easier.

One Unit for Each Property

One of the greatest advantages is that there is only one unit for measuring each physical property. For example, pressure may be measured by psi, psf, kips/sf, inches of mercury or other units in the conventional U.S. system. The SI system has only one unit for pressure, the pascal. Another example involves power, which may be measured in hp, btu's, watts, and several other terms. In SI, it is measured only in watts. Therefore, metric is a more coherent system in that only one unit is used for each physical quantity and there are no conversion factors to remember.

Conclusion

Metric's coherency, its simple base units, and its use of decimal arithmetic make it an especially logical and useful measurement system.

The American construction community is able to meet the metric conversion challenge in federal construction, and it is in our long-term strategic interest to do so.

There will be initial effort involved. Firm resolve, close cooperation between the public and private sectors, and creative application of our extensive talent and expertise will allow the challenge to be successfully met.

METRIC BASE UNITS

The SI "metric" system was not the first metric approach. It was preceded by the cgs (centimeter-gram-second) system and the mks (meter-kilogram-second) system.

In SI, there are seven base units, many derived units, and two supplementary units which are summarized in table 1.2. There are specific definitions of the base units and supplemental units. This section will provide an overview of the metric system with an emphasis on highway engineering related units of length, mass, time, and temperature.

Table 1.2. Overview of SI.

	Units	*Symbol*
Base units		
length	meter	m
mass	kilogram	kg
time	second	s
temperature*	kelvin	K
electrical current	ampere	A
luminous intensity	candela	cd
amount of material	mole	mol
Derived units	**	
Supplementary units		
angles in the plane	radian	rad
solid angles	steradian	sr

*We will use degrees Celsius (°C), which has a more common usage than kelvin.
** Many derived units exist; several will be discussed in this session.

The base units uniquely describe a property requiring measurement. The seven base units are length, mass, time, temperature, electrical current, luminous intensity, and amount of material. These units are dimensionally independent.

Length

One of the most common units in civil engineering and other disciplines is length. In SI, the base length unit is the meter. The meter, and a few of its sub-multiples, are presented in figure 1.1.

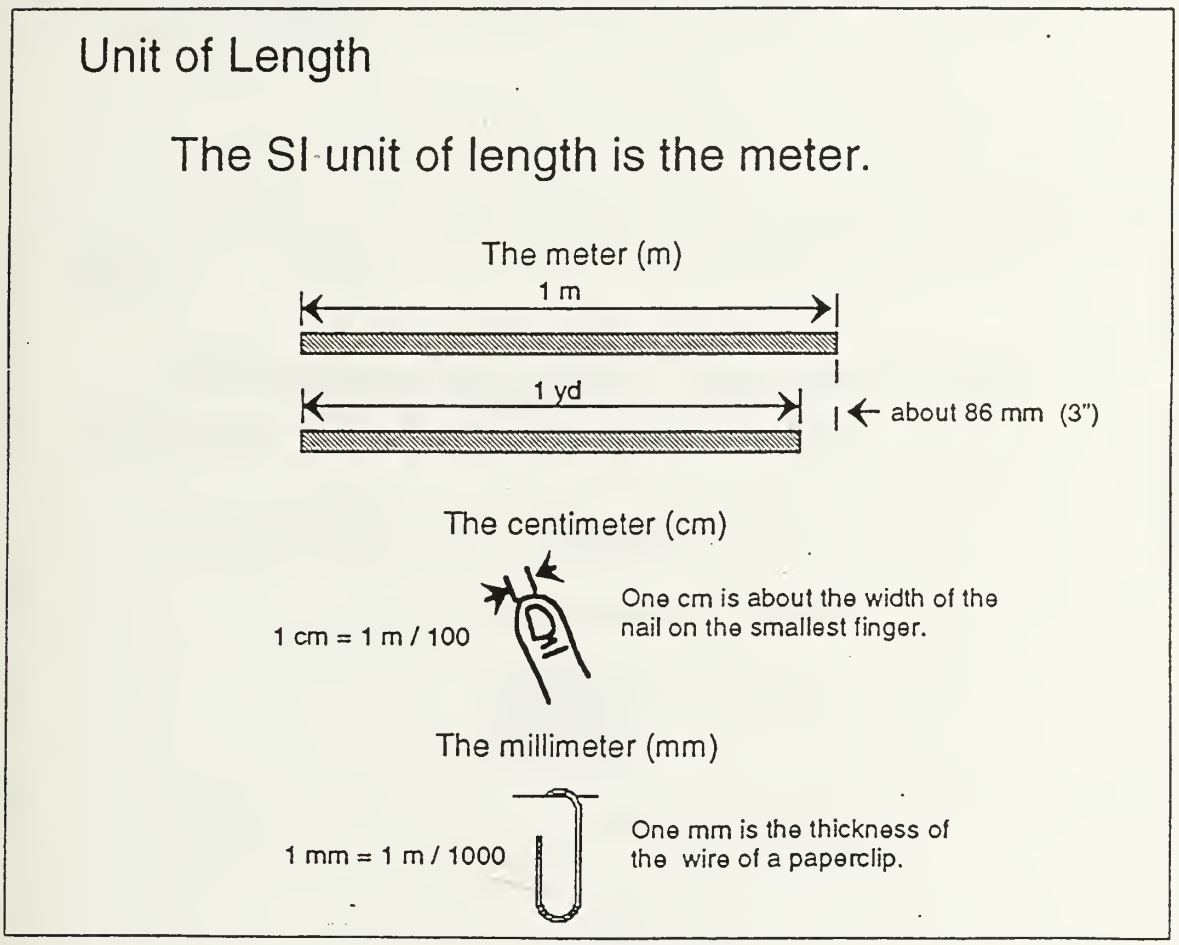

Unit of Length
The SI unit of length is the meter.
The meter (m)
1 m
1 yd
about 86 mm (3")
The centimeter (cm)
1 cm = 1 m / 100
One cm is about the width of the nail on the smallest finger.
The millimeter (mm)
1 mm = 1 m / 1000
One mm is the thickness of the wire of a paperclip.

Figure 1.1. Unit of length.

TIME

The base unit for time is the second.

Mass

The second base unit relevant to highway applications is the kilogram which is a measure of mass. Mass is the measurement of inertia of an object. It may be thought of as the measure of an object's resistance to acceleration. Mass is illustrated in figure 1.3.

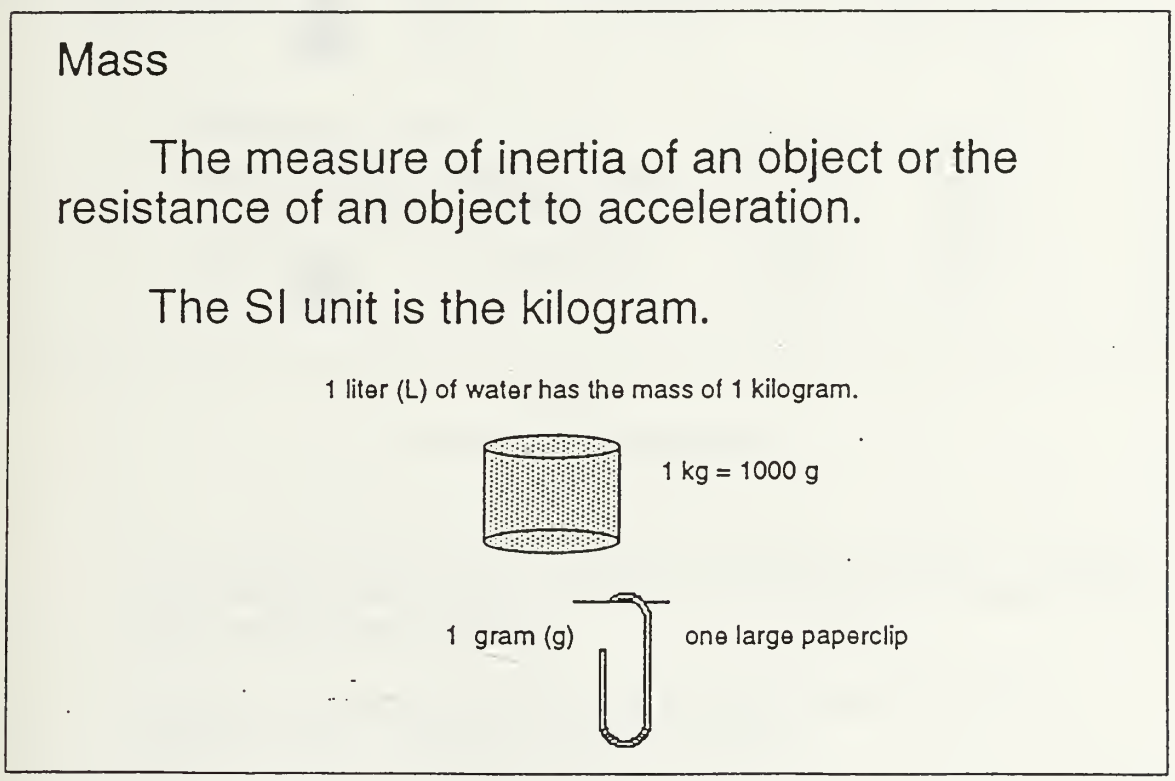

Mass
The measure of inertia of an object or the resistance of an object to acceleration.
The SI unit is the kilogram.
1 liter (L) of water has the mass of 1 kilogram.
1 kg = 1000 g
1 gram (g)
one large paperclip

Figure 1.3. Mass.

Temperature

Temperature is another base unit with usage in highway applications especially in material testing procedures and construction specifications. Kelvin is the base SI temperature unit with the Celsius scale being closely related, as shown in figure 1.5.

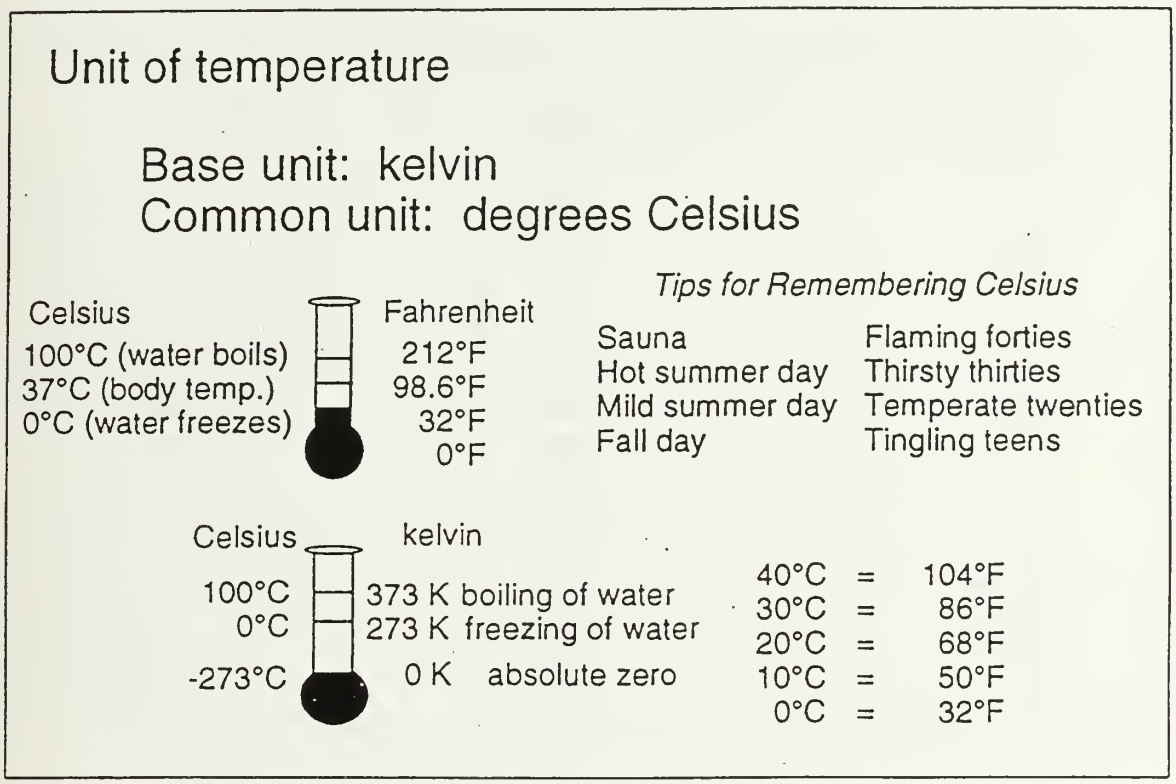


Figure 1.5. Temperature.

- The Celsius scale is the metric temperature scale that the public will learn, e.g., through weather reports. It is based on freezing and boiling points of water at atmospheric pressure.

- The kelvin scale is used in science and engineering, and it is the SI temperature scale. There are no negative values.

DERIVED UNITS

Derived units are formed by combining base units to express other characteristics. Velocity (m/s), slope (m/m), and density (kg/m^3) are derived measures. Many others have their own special unit name. Table 1.3 summarizes many of these units. The relationships between all derived units remain on a decimal basis.

Table 1.3. Derived units with special names.

Quantity	Name	Symbol	Expression
frequency	hertz	Hz	s^{-1}
force	newton	N	$kg \cdot m/s^2$
pressure, stress	pascal	Pa	N/m^2
energy, work, quantity of heat	joule	J	$N \cdot m$
power, radiant flux	watt	W	J/s
electric charge, quantity	coulomb	C	$A \cdot s$
electric potential	volt	V	W/A
capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
electric conductance	siemens	S	A/V
magnetic flux	weber	Wb	$V \cdot s$
magnetic flux density	tesla	T	Wb/m^2
inductance	henry	H	Wb/A
luminous flux	lumen	lm	$cd \cdot sr$
illuminance	lux	lx	lm/m^2

Area and volume are common derived units which have many variations. The liter is a special metric unit for volume which is slightly larger than a quart. Some of these are shown in figure 1.6.

The use of other derived units depends upon the context. For example, energy and torque are dimensionally equivalent, but represent different concepts. Energy is written with units of joule which is a special name for N · m, while Torque is always written as N · m rather than as joule. These are also illustrated in figure 1.6.

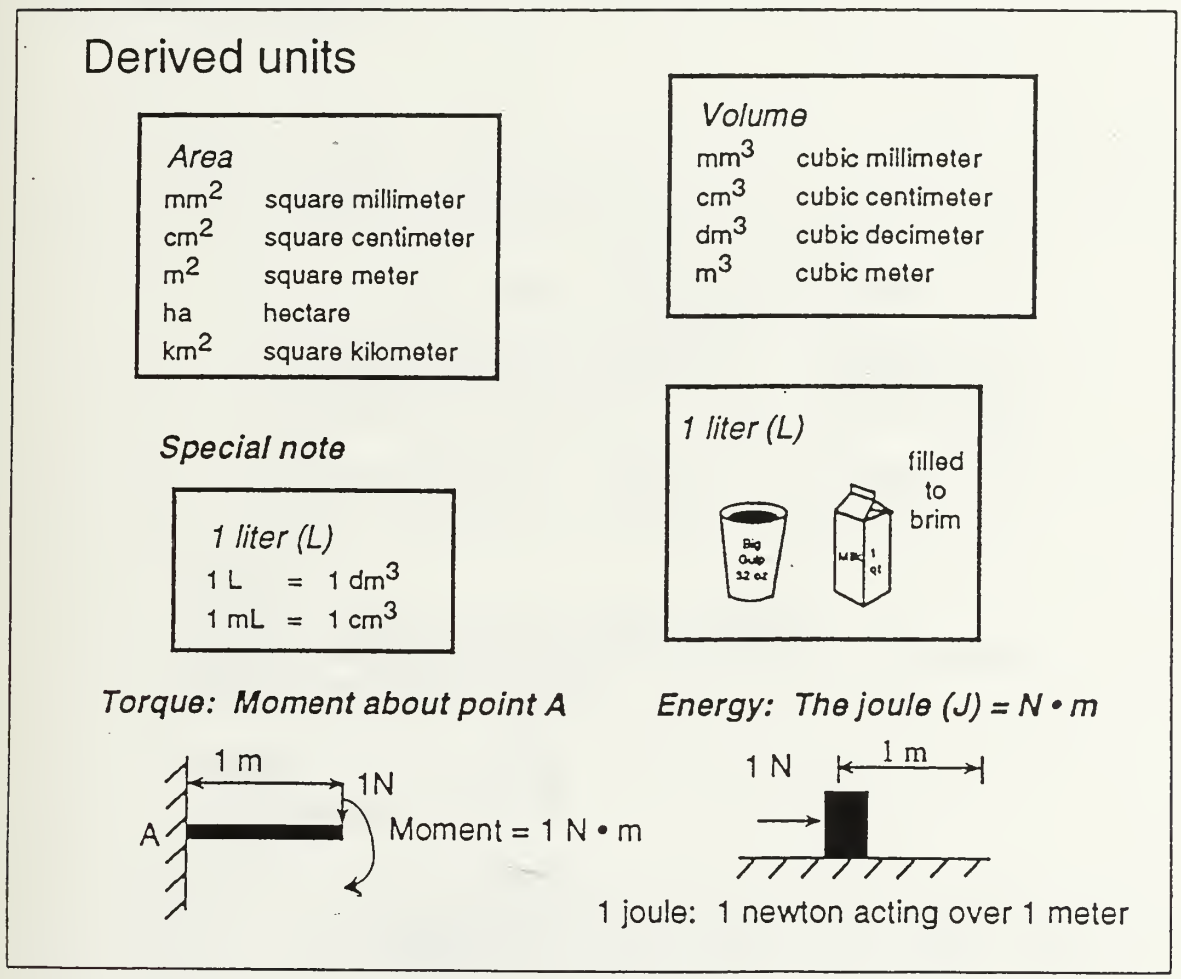


Figure 1.6. Derived units.

MASS AND WEIGHT

A subtle distinction exists between "mass" and "weight": "mass" is a base quantity while "weight" is a derived quantity related to mass and the acceleration due to gravity. Weight is sometimes referred to as the force of gravity. A person's mass does not change when walking on the moon versus the earth, but the person's weight does. The weight of an object is a function of the gravitational pull on the object. Figure 1.7 illustrates this distinction. In English units, one tends to operate in terms of weight (pounds) primarily. If mass is needed, one divides by the acceleration due to gravity (32.2 ft/s^2) to find slugs or pounds-mass. In SI units, mass is the base quantity, and force of gravity is calculated by multiplying by the acceleration due to gravity (9.81 m/s^2). Loosely speaking, it is common to convert pounds to kilograms by dividing by 2.2. This can only be applied on earth (home of most highway projects).

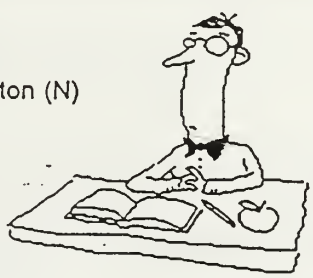
	mass	weight or force of gravity	force
English	slug pound-mass	pound pound-force	pound pound-force
metric	kilogram	newton	newton

Example:

On Earth, the acceleration due to gravity = 9.81 m/s^2.
Therefore, a 1 kg object placed on a structure will impose a force of gravity of 9.81 N. It also weighs 2.2 pounds.

Weight:

The newton (N)



220 lb man on Earth = weighs 981 N

220 lb man on Earth = mass of 100 kg.

Figure 1.7. Mass and weight.

SUPPLEMENTARY UNITS

The supplementary units radian and steradian are regarded as dimensionless derived units which express plane and solid angles, respectively. The radian is the plane angle when the arc length of a circle is equal to the radius of the circle. The steradian is the solid angle when the surface area of a portion of a sphere is equal to the radius of the sphere squared. They are illustrated in figure 1.8.

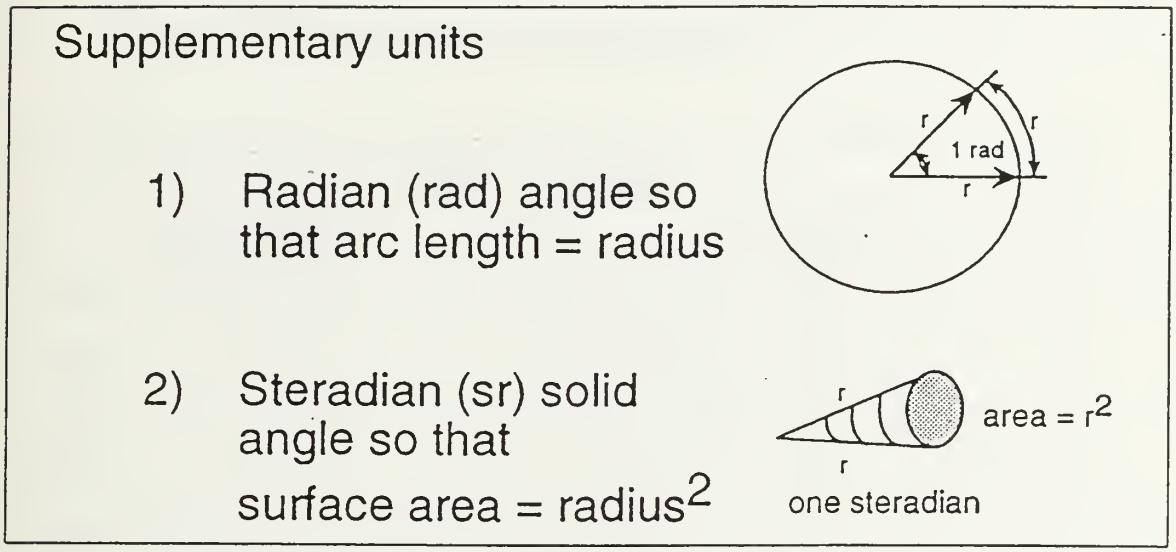


Figure 1.8. Angles.

Supplementary units are dimensionless, but do have a specific purpose.

- 360 degrees = 2π radians
- A sphere has 4π steradians
- circumference = $2\pi r$
- surface area = $4\pi r^2$

The SI unit for plane angle is the radian. Use of the degree, minute, and second is permissible when the radian is not a convenient unit. Use of the minute and second is discouraged except for special fields such as surveying and cartography.

NOMENCLATURE

The metric system includes an organized nomenclature for describing various units and their multiples as well as proper ways of writing metric names and symbols. The logical and consistent method of expressing metric units of measure is part of the system's appeal.

One reason the metric system is preferred is because each unit of measure has two parts: a prefix and a base unit.

- The prefix is the part that gives the relative size. The same prefixes are applied to all unit names, and they are summarized in table 1.4. For example, a millimeter represents 1/1000th of a meter.

- The base unit gives the type of measurement.

Table 1.4. Prefixes.

Submultiples			*Multiples*		
deci	10^{-1}	d	deka	10^{1}	da
centi	10^{-2}	c	hecto	10^{2}	h
milli	10^{-3}	m	kilo	10^{3}	k
micro	10^{-6}	μ	mega	10^{6}	M
nano	10^{-9}	n	giga	10^{9}	G
pica	10^{-12}	p	tera	10^{12}	T
femto	10^{-15}	f	peta	10^{15}	P
atto	10^{-18}	a	exa	10^{18}	E
zepto	10^{-21}	z	zetta	10^{21}	Z
yocto	10^{-24}	y	yotto	10^{24}	Y

The symbols representing prefixes are shortened forms of the prefixes. The symbol for "micro" is the Greek letter μ or "mu" and is used because "m" is already used. "da" is used for "deka" and is the only symbol with two letters for abbreviation. The use of capital letters versus lower case letters does bear a significance. For example, "M" vs. "m" have different meanings; "M" means "mega" and "m" means "milli."

Rules for Writing Symbols and Names

- Print unit symbols in upright type and in lower case except for liter (L) or unless the unit name is derived from a proper name.
- Print unit names in lower case, even those derived from a proper name.
- Print decimal prefixes in lower case for magnitudes 10^3 and lower (i.e. k, m, μ, and n) and print the prefixes in upper case for magnitudes 10^6 and higher (i.e. M and G).
- Leave a space between a numeral and a symbol (write 45 kg or 37°C, not 45kg or 37 °C or 37° C).
- Do not use a degree mark (°) with kelvin temperature (write K, not °K).
- Do not leave a space between a unit symbol and its decimal prefix (write kg, not k g).
- Do not use the plural of unit symbols (write 45 kg, not 45 kgs), but do use the plural of written unit names (several kilograms).
- For technical writing, use symbols in conjunction with numerals (the area is 10 m^2); write out unit names if numerals are not used (carpet is measured in square meters). Numerals may be combined with written unit names in nontechnical writing (10 meters).
- Indicate the product of two or more units in symbolic form by using a dot positioned above the line ($kg \cdot m/s^2$).
- Do not mix names and symbols (write N•m or newton meter, not N•meter or newton•m).
- Do not use a period after a symbol (write 12 g, not 12 g.) except when it occurs at the end of a sentence.
- Where modules are used, the recommended basic module is 100 mm, which is similar to the 4-inch module used in building construction (4 inches = 101.6 mm).

UNITS USED ON DRAWINGS

- Label all dimensions on all drawings unless an explanatory note is used (i.e., "All dimensions are shown in millimeters" or "All dimensions are shown in meters"). It is good design practice to label all elevations, dimensions, etc., with the proper units particularly during the interim conversion period.

Rules for Writing Numbers

- Always use decimals, not fractions (write 0.75 g, not ¾ g).
- Use a zero before the decimal marker for values less than one (write 0.45 g, not .45 g).
- Use spaces instead of commas to separate blocks of three digits for any number over four digits (write 45 138 kg or 0.004 46 kg or 4371 kg). Note that this does not apply to the expression of amounts of money.
- In the United States, the decimal marker is a period; in other countries a comma usually is used.

COHERENCY

SI is a "coherent" system of measurement because all of its units are formed by multiplying or dividing base units using only the factor of one. This is not true of the English system. Therefore, conversion within the metric system from one unit to another is very simple. The only thing that changes is the location of the decimal point.

A measurement system is coherent if:

- All derived and supplementary units are formed by multiplying and/or dividing base units.
- The above multiplication only involves the numeric factor of one (1).

Coherent examples:

Force = mass x acceleration
one newton = one kilogram x one meter / (one second)^2

METRIC CONSTRUCTION GUIDES

American Society for Testing and Materials (1916 Race Street, Philadelphia, PA 19103, Phone: (215)299-5585):

- *ASTM E621, Standard Practice for the Use of Metric (SI) Units in Building Design and Construction, 1984,* 37 pp., 1984, $12.00.

National Institute of Building Sciences (Publications Department, 1201 L Street N.W., Suite 400, Washington, CD 20005, Phone: (202)289-7800):

- *The Metric Guide for Federal Construction,* 1st Edition, Operating Committee of the Interagency Council on Metric Policy, National Institute of Building Sciences (NIBS), Washington, DC, 1991. Written by NIBS specifically for the construction industry and reviewed by metric experts throughout the country. Includes background on the federal metric laws; facts on metric in construction; an introduction to metric units; a primer on metric usage for architects, engineers, and the trades; requirements for metric drawings and specifications; guidance on metric management and training; and a list of current metric construction references. 34 pp., $15.00 (including shipping and handling).

- *GSA Metric Design Guide.* Interim design guide developed by the General Services Administration (GSA) for use by federal project managers and their A/Es. Contains practical architectural, civil, structural, mechanical, and electrical design information; a list of available "hard" metric products; sample drawings; and related reference information. 77 pp., $8.00; $5.00 if ordered with the above *Metric Guide for Federal Construction.*

National Technical Information Service (5285 Port Royal Rd., Springfield, VA 22161, Phone: (703)487-4600).

- NBS Technical Note 990, *The Selection of Preferred Metric Values for Design and Construction.* H.J. Milton, author, 75 pp.

GENERAL METRIC INFORMATION

American Association of State and Highway Transportation Officials (444 N. Capital St., N.W., Suite 225, Washington, DC 20001; Phone (202)624-5800):

- *Guide to Metric Conversion.*

American National Metric Council (Washington, DC; Phone (410)727-0882 for publications):

- *ANMC Metric Editorial Guide*, $5.00.
- *SI Metric Training Guide*, $5.00.
- *Metrication for the Manager*, $15.00.

National Technical Information Service (5285 Port Royal Rd., Springfield, VA 22161; Phone: (703)487-4600):

- PB 89-226922, *Metric Handbook for Federal Officials* (includes Federal Standard No. 376A of May 5, 1983, *Preferred Metric Units General Use by the Federal Government*), 45 pp., 1989, $17.00.

U.S. Government Printing Office (Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402; Phone: (202)783-3238):

- NIST Special Publication 33, 1991 Edition, *The International System of Units (SI)*, 56 pp., August, 1991, $3.50.
- NIST Special Publication 811, *Guide for the Use of International System of Units*, Arthur O. McCoubrey, author, 34 pp., September, 1991, $2.50.
- "Metric System of Measurement: Interpretation of the International System of Units for the United States: Notice, *Federal Register*, December 20, 1990.

U.S. Metric Association (10245 Andasol Ave., Northridge, CA 91325; Phone: (818)363-5606):

- *Style Guide to the Use of the Metric System*, $3.00; bulk discounts available.
- *SI Metric Style Guide for Written and Computer Usage*, $2.00; bulk discounts available.
- *Freeman Training/Education Metric Materials List*, $38.00.
- *Metric Vendor List*, $28.00.

STANDARDS & SPECIFICATIONS

American Association of State and Highway Transportation Officials (444 N. Capital St., N.W., Suite 225, Washington, DC 20001; Phone (202)624-5800):

- *Standard Specifications for Transportation Materials*. Two-volume set, includes dual units, $115.00.
- *A Policy on Geometric Design of Highway and Streets*, 1990.
    - *Interim Selected Metric Values for Geometric Design*.

American National Standards Institute, Inc. (11 West 42nd St., New York, NY 10036; Phone: (212)642-4900):

- ANSI/IEEE 268, *American National Standard Metric Practice*, 48 pp., 1982, $23.00.

American Society for Testing and Materials (1916 Race St., Philadelphia, PA 19103; Phone: (215)299-5585):

- ASTM E380, *Standard Practice for Use of the International System of Units (SI)*, 35 pp., 1992, $23.00.

CIVIL

American Congress on Surveying and Mapping (5411 Grosvenor Lane, Suite 100, Bethesda, MD 20814; Phone (301)493-0200):

- *Metric Practice Guide for Surveying and Mapping*, 11 pp., 1978, $10.00.

American National Metric Council (1735 N. Lynn St., Suite 950, Arlington, VA 22209; Phone: (703)524-2007):

- *ANMC Metric Editorial Guide*, Fourth edition, 16 pp., 1990, $2.00.
- *SI Metric Training Guide*, 17 pp., 1991.
- *Managing Metrication in Business and Industry*, 203 pp., 1976.

STEEL

American Institute of Steel Construction (Metric Publications, One E. Wacker Dr., Suite 3100, Chicago, IL 60601-2001; Phone: (312)670-5414):

- *Metric Properties of Structural Shapes with Dimensions According to ASTM A6M*, Metric version of Part I of the *Manual of Steel Construction*, $10.00.
- *Manual of Steel Construction, Metric Edition*, to be published in 1994.
- *Load and Resistance Factor Design*, 1986.

Industrial Fasteners Institute (1105 East Ohio Building, 171 E. 9th St., Cleveland, OH 44114; Phone: (216)241-1482):

- *Metric Fastener Standards*, $60.00.

STRUCTURES

Florida Wire and Cable Company (P.O. Box 6835, Jacksonville, FL 32236, Phone: (800)874-0093):

- *Physical Properties of Strand, Uncoated, Stress Relieved for Prestressed Concrete Structures.*

Ralph E. Anderson, Chief of Bridges and Structures, Illinois Department of Transportation:

- *Memorandum on Metric Conversions*, March 1, 1993.

American Association of State Highway and Transportation Officials (444 N. Capital St., N.W., Suite 225, Washington, DC 20001; Phone (202)624-5800):

- *Standard Specifications for Highway Bridges*, 1992, with interim 1993.

STANDARDS & SPECIFICATIONS (MDT)

Montana Department of Transportation (2701 Prospect Avenue, P.O. Box 201001, Helena, MT 5962-1001):

- *Standard Specifications for Road and Bridge Construction*, 667 pp., 1987 edition (includes Supplemental Specifications).
- *MDT Materials Manual*, published and updated by the MDT Materials Bureau.
- *MDT Survey Manual*, published and updated through the Construction Bureau and Photogrammetry and Survey Section.

DRAWING SIZES

The ISO "A" series drawing sizes are preferred metric sizes for design drawings. There are five "A" series sizes:

ISO Designation	Metric Sheet Size	Replaces	Current MDT Sizes
A0	841 x 1189 mm	34 x 44 inches	--
A1	594 x 841 mm	22 x 34 inches	559 mm x 864 mm (D)
A2	420 x 594 mm	17 x 22 inches	--
A3	297 x 420 mm	11 x 17 inches	279 mm x 432 mm (B)
A4	210 x 297 mm	8½ x 11 inches	216 mm x 279 mm (A)

Sheet size "A0" is the base drawing with an area of one square meter. Smaller sizes are obtained by halving the long dimension of the previous size. All "A" size have a height to width ratio of one to the square root of two.

All full-sized plan sheets should conform to the "A1" metric series size. Existing size D paper will be used until metric paper is available. Drawing borders of 13 mm will be used at the top and bottom and 13 mm at the right edge. The left border (binding edge) will be 51 mm. The 2.9" excess width should be added to the left (binding edge) border of size D paper.

HYDRAULICS

Nominal Sizes-RCP	
ISO (mm)	English (in.)
300	12
375	15
450	18
525	21
600	24
675	27
750	30
825	33
900	36
1050	42
1200	48
1350	54
1500	60
1650	66
1800	72
1950	78
2100	84

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1, "M170M.

Note: RCP will be identified by the metric sizes shown above. Until the industry converts to metric, there will be no physical product change. Current accepted tolerances allow English sizes to meet metric size requirements.

CORRUGATED STEEL PIPE

68 mm x 13mm Corrugations
(2⅔ in. x ½ in. Corrugations)

PIPE DIAMETER	
ISO (mm)	ENGLISH (in.)
300	12
400	15
450	18
500	21
600	24
700	-
800	30
900	36
1000	42
1200	48
1400	54
-	60
1600	-
-	66
1800	72
2000	78

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1," M36M.

Note: CSP will be hard converted to metric sizes. In other words, there will be a physical product change and the metric sizes will approximate the previous English sizes as shown above.

CORRUGATED STEEL PIPE (CONT.)

75 mm x 25 mm or 125 mm x 25 mm Corrugations
(3 in. x 1 in. or 5 in. x 1 in. Corrugations)

PIPE DIAMETER	
ISO (mm)	ENGLISH (in.)
1400	54
-	60
1600	-
-	66
1800	72
2000	78
2200	84
-	90
2400	96
-	102
2700	108
-	114
3000	120

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1," M36M.

Note: CSP will be hard converted to metric sizes. In other words, there will be a physical product change and the metric sizes will approximate the previous English sizes as shown above.

Right-of-Way Bureau Guidelines

1. Introduction

The following guidelines identify the method and procedures for metric conversion in the R/W Bureau. The Preconstruction Bureau develops the base map for our various R/W plans.

We will follow the suggested guideline to show some dual dimensions on the R/W, Utility, and Railroad plans and deed exhibits. Dual measurements will be shown for recorded distances and metrics only will be shown for new measurements. Areas will be shown in both metric and English.

2. Implementation

When a project is identified with the centerline in metrics R/W guidelines for metrics will be used. Projects now being worked on may be converted to metric measurements if the Preconstruction Bureau changes the centerline to metrics. If a project has already been authorized for acquisition using a non-metric centerline the R/W plans are not to be revised to metrics.

3. Plan Preparation

a. Design - New widths of R/W will be set in increments of five meters (i.e. - 20, 25, 30, etc.). It is preferred that this measurement is to be measured from the centerline, but may be an additional distance from the existing roadway or property line.

- Collector Routes - The minimum standard total width of R/W will be 20 m on each side of the centerline.

- Arterial Routes - The minimum standard total width of R/W will be 25 m on each side of the centerline.

Existing right-of-way widths will be shown in meters rounded to two decimal places.

b. Scale - The bar scale in metrics will be shown on each sheet. (OPTION: The English measurement may also be shown on the bar scale.)

- R/W Plan sheets will generally be shown for:
  rural area on a scale of 1:1000
  urban area on a scale of 1:500

- Ownership maps will generally be shown on a scale of 1:5000

- R/W exhibits will generally be shown to the same scale or half scale of the R/W plan sheets.

STATIONING AND CROSS-SECTIONS

A station concept based on 100 meters (1+00) will be used for metric plans. For example, Station 12+27.39 indicates a point 27.39 m forward of Station 12+00.

Use an equivalent conversion from English to metric when re-establishing points from a previously run survey. For example, P.I. Station 456+35.00 from a 1965 survey using English units would be defined as Station 139+09.55 (45 635 ft. x 0.304 8 m/1 ft = 13 909.55 m) in a metric survey. The 100 meter stationing on new alignments is arbitrary, but is the standard chosen by MDT.

Standard cross-section intervals of 20 meters rural and 10 meters urban should be used where alignment is maintained over existing embankments and through rolling terrain. Although 20 meters should be considered the standard, a larger interval may be considered when uniform templates are used over flat terrain. Additional cross-sections should be provided to reflect abrupt changes in either the template or the existing ground.

The usual horizontal and vertical cross-section scale is 1:100 [Use 1 m - 100 m]; 1:200 is also acceptable, where greater width or height is required.

RECOMMENDED CURVE RADII			
Select curve radii from the following:			
Approximate Degree of Curvature	Metric Radius	Approximate Degree of Curvature	Metric Radius
0°15'	7000 m	4°00'	450 m
0°30'	3500 m	5°00'	350 m
0°45'	2350 m	6°00'	300 m
1°00'	1750 m	7°00'	250 m
1°30'	1150 m	8°00'	220 m
2°00'	900 m	9°00'	190 m
2°30'	700 m	10°00'	170 m
3°00'	600 m	11°00'	160 m
3°30'	500 m	12°00'	150 m

From Chapter 9, MDT Road Design Manual

Area, Length, and Volume Conversion Factors

Quantity	From English Units	To Metric Units	Multiply By
Length	mile	km	1.609 344
	yard	m	0.914 4
	foot	m	0.304 8
	foot	mm	304.8
	inch	mm	25.4
Area	square mile	km^2	2.590
	acre	m^2	4 046.856
	acre	ha (10 000 m^2)	0.404 685 6
	square yard	m^2	0.836 127 36
	square foot	m^2	0.092 903 04
	square foot	ha (10 000 m^2)	0.000 009 29
	square inch	mm^2	645.16
Volume	acre foot	m^3	1 233.49
	cubic yard	m^3	0.764 555
	cubic foot	m^3	0.028 316 8
	cubic foot	cm^3	28 316.85
	cubic foot	L (1000 cm^3)	28.316 85
	100 board feet	m^3	0.235 974
	gallon	L (1000 cm^3)	3.785 41
	1000 gallons	kL (1000 L)	3.785 41
	cubic inch	cm^3	16.387 064
	cubic inch	mm^3	16 387.064

NOTE: Underline denotes exact number

Civil and Structural Engineering Conversion Factors

Quantity	From English Units	To Metric Units	Multiply By
Mass	lb kip (1000 lb)	kg metric ton (1000 kg)	0.453 592 0.453 592
Mass/unit length	plf	kg/m	1.488 16
Mass/unit area	psf	kg/m^2	4.882 43
Mass density	pcf	kg/m^3	16.018 5
Force	lb kip	N kN	4.448 22 4.448 22
Force/unit length	plf klf	N/m kN/m	14.593 9 14.593 9
Pressure, stress, modulus of elasticity	psf ksf psi ksi	Pa kPa kPa MPa	47.880 3 47.880 3 6.894 76 6.894 76
Bending moment, torque, moment of force	ft-lb ft-kip	N·m kN·m	1.355 82 1.355 82
Moment of mass	lb-ft	kg·m	0.138 255
Moment of inertia	$lb\text{-}ft^2$	$kg\cdot m^2$	0.042 140 1
Second moment of area	in^4 ft^4	mm^4 m^4	416 231 0.008 63
Section modulus	in^3	mm^3	<u>16 387.064</u>

NOTE: Underline denotes exact number.

Conversion and Rounding

- When converting numbers from English to metric, generally round the metric value to the same number of digits as there were in the English number (11 miles at 1.609 km/mi equals 17.699 km, which rounds to 18 km).

- Convert mixed English units (feet and inches, pounds and ounces) to the smaller English unit before converting to metric and rounding (10 feet, 3 inches = 123 inches; 123 inches x 25.4 mm/in = 3124.2 mm; round to 3124 mm).

- In a "soft" conversion, an English measurement is mathematically converted to its exact (or nearly exact) metric equivalent. With "hard" conversion, a new rounded, rationalized metric number is created that is convenient to work with and remember.

Visualizing Metric

- One millimeter is about 1/25 inch or slightly less than the thickness of a dime. One meter is the length of a yardstick plus about 3⅓ inches.
  One gram is about the mass (weight) of a large paper clip.
  One kilogram is about the mass (weight) of a softbound model building code book (2.2 pounds).
  One liter is about the volume of a 4-inch cube (100 mm x 100 mm x 100 mm). One liter of water has a mass of 1 kilogram.

- One inch is just a fraction (1/64-inch) longer than 25 mm (1 inch = 25.4 mm; 25 mm = 63/64-inch).
  Four inches are about 1/16 inch longer than 100 mm (4 inches = 101.6 mm; 100 mm = 3-15/16 inches).
  One foot is about 3/16 inch longer than 300 mm (12 inches = 304.8 mm; 300 mm = 11-13/16 inches).
  Four feet are about ¾-inch longer than 1200 mm (4 feet = 1219.2 mm; 1200 mm = 3 feet, 11 ¼ inches).

- The metric equivalent of a typical 2-foot by 4-foot ceiling grid is 600 x 1200 mm, so metric ceiling tiles and lighting fixtures are about 3/8-inch smaller in one dimension and ¾-inch smaller in the other dimension.

- Similarly, the metric equivalent of a 4 by 8 sheet of plywood or drywall is 1200 x 2400 mm, so metric sheets are about ¾-inch narrower and 1½ inches shorter.

- "Rounding down" from multiples of 4 inches to multiples of 100 mm makes dimensions exactly 1.6 percent smaller and areas about 3.2 percent smaller. About 3/16-inch is lost in every linear foot.

Soft Metric

- Soft Metric means "No Physical Change". This implies the product in question will not be physically modified to be used in a metric project.
- All that is required is that the product literature and engineering data on these products be available with metric dimensions. It is acceptable if product literature contains both metric and English dimensions. Since product literature costs can be substantial, firms without metric product literature need only develop a supplement to their existing literature. Supplements will be accepted as submittals for an interim period.
- There is no problem with competitive availability of soft converted products on a metric project, since these same products are competitively available today.
- In the future, as standard international metric product sizes are developed by ISO (International Standard Organization) or another standards organization, these products may undergo modification to be compatible in the world market.

Hard Metric

- Hard Metric means "Product Requires Physical Change." The product in question must be physically modified in order to be efficiently utilized in a metric project, which is planned on a metric grid.
- A handful of currently used construction products must undergo hard conversion to new metric sizes.

Conversion and Rounding

- When converting numbers from English to metric, generally round the metric value to the same number of digits as there were in the English number (11 miles at 1.609 km/mi equals 17.699 km, which rounds to 18 km).

- Convert mixed English units (feet and inches, pounds and ounces) to the smaller English unit before converting to metric and rounding (10 feet, 3 inches = 123 inches; 123 inches x 25.4 mm/in = 3124.2 mm; round to 3124 mm).

- In a "soft" conversion, an English measurement is mathematically converted to its exact (or nearly exact) metric equivalent. With "hard" conversion, a new rounded, rationalized metric number is created that is convenient to work with and remember.

- Wherever possible, convert measurements to rounded, rationalized "hard" metric numbers. For instance, if anchor bolts are to be embedded to a depth of 10 inches, the exact converted length of 254 mm might be rounded to either 250 mm (9.84 inches) or 260 mm (10.24 inches). The less critical the number, the "rounder" it can be, but ensure that allowable tolerances or safety factors are not exceeded. **When in doubt, stick with the exact "soft" conversion.**

- Round to "preferred" metric numbers. While the preferred numbers for the " 1 foot = 12 inches" system are, in order of preference, those divisible by 12, 6, 4, 3, 2 and 1, preferred metric numbers are, in order of preference, those divisible by 10, 5, 2 and 1 or decimal multiples thereof.

- Use hand calculators or software conversion programs that convert English units to metric. They are readily available and are indispensable to the conversion process. Simply check with any store or catalogue source that sells calculators or software.

- Be careful with the decimal marker when converting areas and volumes; metric numbers can be significantly larger than English numbers (a cubic meter, for instance, is one billion cubic millimeters).

EXAMPLES OF CALCULATIONS AND ROUNDING:

130 feet	X	0.304 8	=	39.62 meters (soft conversion) 40 meters (hard conversion)
2100 square feet	X	0.092 903 04	=	195.10 square meters (soft conversion) 195 square meters (hard conversion)
2.30 acres	X	0.404 685 6	=	0.931 hectares (soft conversion) 0.93 hectares (hard conversion)
25 meters	X	3.280 839 90	=	82.02 feet (soft conversion) 82 feet (hard conversion)
214.61 sq. meters	X	10.763 910 42	=	2310.04 square feet (soft conversion) 2310 square feet (hard conversion)
0.661 hectares	X	2.471 054 07	=	1.63 acres (soft conversion) 1.63 acres (hard conversion)

IMPACTS TO THE MDT

METRIC PROJECT DEFINITION

A project is "metric" when:

- Specifications show SI units only
- Drawings show SI units only
- Construction takes place in SI units only
- Inspection occurs in SI units only
- Cost estimating is based on SI units only

METRIC PRODUCTS

This does not imply that construction products must change. Over 95% of the products used in construction today will undergo no physical change at all during the metric transition. All that will occur is that the dimensions of the product will be identified in drawings, specifications, and on product literature in metric units, a process called soft conversion.

There are a handful of products that must undergo a physical change now in order to be efficiently used in metric construction. This process is called hard conversion. As international standards are developed for more products, American products will then be hard converted to those sizes, to enhance their export potential.

Bolt diameters are taken directly from the ASTM Specification A325 and A490M. The metric bolt designations are as follows:

Designation	Diameter (mm)	Diameter (in.)
M16	16	0.63
M20	20	0.79
M22	22	0.87
M24	24	0.94
M27*	27	1.06
M30*	30	1.18
M36*	36	1.42

*Not currently used by MDT Bridge Bureau

REINFORCING STEEL

Metric projects will use ASTM A615M reinforcing bars, which come in Grades 300 and 400 (indicating 300 and 400 MPa yield strengths), for general purpose applications. Metric rebars vary based on round values of cross-sectional area, which are specified by nominal diameter at 5 mm increments. There are 8 bar sizes, which replace the 11 bar sizes currently being used. While many firms can make metric rebar, minimum order quantities apply. It should be determined for each project if metric rebar is feasible, or if existing sizes should be used.

The following table shows the available metric rebar sizes and the current U.S. customary rebar sizes in relationship to the respective diameters and cross-sectional areas.

Metric Bar Designation	U.S. Customary Designation	Customary English System		Metric Equivalent	
		Diameter (in.)	Area ($in.^2$)	Diameter (mm)	Area (mm^2)
	#3	0.375	0.11	9.5	71
10				11.3	100
	#4	0.500	0.20	12.7	127
	#5	0.625	0.31	15.9	198
15				16.0	200
	#6	0.750	0.44	19.1	285
20				19.5	300
	#7	0.875	0.60	22.2	388
25				25.2	500
	#8	1.000	0.79	25.4	507
	#9	1.125	1.00	28.6	641
30				29.9	700
	#10	1.270	1.27	32.3	817
35				35.7	1000
	#11	1.410	1.56	35.8	1007
	#14	1.693	2.25	43.0	1452
45				43.7	1500
55				56.4	2500
	#18	2.257	4.00	57.3	2579

IMPACTS TO THE MDT DESIGN PROCESS

RIGHT OF WAY

1. Introduction

The following guidelines identify the method and procedures for metric conversion in the R/W Bureau. The Preconstruction Bureau develops the base map for our various R/W plans.

We will follow the suggested guideline to show some dual dimensions on the R/W, Utility, and Railroad plans and deed exhibits. Dual measurements will be shown for recorded distances and metrics only will be shown for new measurements. Areas will be shown in both metric and English.

2. Implementation

When a project is identified with the centerline in metrics R/W guidelines for metrics will be used. Projects now being worked on may be converted to metric measurements if the Preconstruction Bureau changes the centerline to metrics. If a project has already been authorized for acquisition using a non-metric centerline the R/W plans are not to be revised to metrics.

3. Plan Preparation

a. Design - New widths of R/W will be set in increments of five meters (i.e. - 20, 25, 30, etc.). It is preferred that this measurement is to be measured from the centerline, but may be an additional distance from the existing roadway or property line.

- Collector Routes - The minimum standard total width of R/W will be 20 m on each side of the centerline.

- Arterial Routes - The minimum standard total width of R/W will be 25 m on each side of the centerline.

Existing right-of-way widths will be shown in meters rounded to two decimal places.

b. Scale - The bar scale in metrics will be shown on each sheet. (OPTION: The English measurement may also be shown on the bar scale.)

- R/W Plan sheets will generally be shown for:
  rural area on a scale of 1:1000
  urban area on a scale of 1:500

- Ownership maps will generally be shown on a scale of 1:5000

- R/W exhibits will generally be shown to the same scale or half scale of the R/W plan sheets.

DRAWING SCALES

Metric drawing scales are expressed in non-dimensional ratios. Nine scales are preferred: 1:1 (full size), 1:5, 1:10, 1:20, 1:50, 1:100, 1:200, 1:500, and 1:1000. Three others have limited usage: 1:2, 1:25, and 1:250.

Drawing Usage	Metric Scales		English Scales	Percent Enlargement or Reduction Using Metric Scale
	Preferred	Other		
Strip Maps	1:1		Full size	No change
		1:2	Half size	No change
	1:5		1" = ¼' 1" = ⅓'	-40% -20%
	1:10		1" = 1'	+20%
	1:20		1" = 2'	+20%
		1:25	1" = 2'	-4%
Typical Section	1:50		1" = 5'	+20%
Cross Sections[1]	1:100		1" = 10'	+20%
Cross Sections[1] and Details	1:200		1" = 20'	+20%
Details		1:250	1" = 20'	-4%
Plan & Profile[2] (Urban)	1:500		1" = 30' 1" = 40' 1" = 50'	-28% -4% +20%
Plan & Profile[2] (Rural)	1:1000		1" = 60' 1" = 100'	-28% +20%

[1]The vertical scale will be a 1:1 proportion of the horizontal scale.
[2]The vertical scale will be a 1:10 proportion of the horizontal scale.

ELEVATION AND CONTOUR INTERVALS

Benchmark elevations will be directly converted from feet to meters. For example, a benchmark elevation of 639.28 feet will be converted directly to 194.853 meters (639.28 ft. x 0.304 8 m/1 ft. = 194.853 m). Benchmark elevations should be shown to a 0.001 meter accuracy.

ROAD DESIGN

Circular Curves

SELECTED CURVE FORMULAS

	CURVE SYMBOLS	CURVE FORMULA
Δ =	Deflection Angle, degrees	$T = R(\tan(\Delta/2))$
T =	Tangent Distance = distance from PC to PI = distance from P.I. to P.T.	$L = 2\pi R \Delta/360$
L =	Length of curve in meters = distance from P.C. to P.T. along curve	$E = T(\tan \Delta/4)$
R =	Radius of curve in meters	
E =	Mid ordinate = distance from PI to curve	

Note: Additional formulas are available in Chapter 9, MDT Road Design Manual.

The following table gives minimum rounded radii in meters for limiting values of superelevations for various design speeds.

Design Speed (km/h)	Minimum rounded radius in meters
	8% maximum superelevation
30	30
40	55
50	85
60	125
70	180
80	230
90	305
100	395
110	505

IMPACTS TO THE MDT DESIGN PROCESS

ROAD DESIGN

Design Speed

Metric Value (km/h)	English Equivalent (mph)	Running Speed (km/h)
40 (24.85 mph)	25	40
50 (31.07 mph)	30	47
60 (37.28 mph)	35 & 40	55
70 (43.50 mph)	45	63
80 (49.71 mph)	50	70
90 (55.92 mph)	55	77
100 (62.14 mph)	60	85
110 (68.35 mph)	65 & 70	91

Lane Width

The values established by the AASHTO Task Force on Geometric Design are slightly narrower (ranging from 4 to 10 percent less) than the corresponding Canadian values. Canadian values are set in 0.25 m increments. This level of precision (hundredths of a meter) appears to be excessive for this element. The Task Force believes that precision to 0.1 m is acceptable and has set values accordingly.

Metric Value (m)	English Equivalent (ft.)	Comparison
2.7 (8.86 ft)	9	(1.56% less than 9 ft. lane)
3.0 (9.84 ft)	10	(1.60% less than 10 ft. lane)
3.3 (10.83 ft)	11	(1.55% less than 11 ft. lane)
3.6 (11.81 ft)	12	(1.58% less than 12 ft. lane)

The Task Force believes that the values established correspond with recent research regarding lane widths and safety benefits (reports TRB 214 and NCHRP 15-12 - the latter currently in progress). Furthermore, construction practices and the pavement striping process generally yield lane widths somewhat less than 9, 10, 11, or 12 ft. The metric values established are typically 1.5 percent below the corresponding English values now specified. This difference is considered negligible with respect to safety benefits. Some capacity reduction may theoretically result, but in practical terms, such a reduction is not expected to be significant.

The 14-foot lane width used on many Interstate ramps will have a 4.2 m metric value.

Surfacing thickness will be identified in 5 mm increments.

HYDRAULICS

CORRUGATED STEEL PIPE ARCHES

75 mm x 25 mm Corrugations
or
125 mm x 25 mm Corrugations

ISO		
SPAN (mm)	RISE (mm)	EQUIVALENT DIAMETER (mm)
1330	1030	1200
1550	1200	1400
1780	1360	1600
2080	1530	1800
2230	1700	2000
2500	1830	2200
2800	1950	2400
3300	2080	2700

3 in. x 1 in Corrugations
or
5 in. x 1 in. Corrugations

English		
SPAN (in)	RISE (in)	EQUIVALENT DIAMETER (in)
53	41	48
60	46	54
66	51	60
73	55	66
81	59	72
87	63	78
95	67	84
103	71	90
112	75	96
117	79	102
128	83	108

Table values from AASHTO Materials, Standard Specifications for Transportation Materials, Part 1," M36M.

Note: 1. CSP arches will be hard converted to metric sizes. In other words, there will be a physical product change and the metric sizes will approximate the previous English sizes as shown above.

2. English to metric conversion cannot be read directly across in these tables, consult the Hydraulics Section for equivalent arch sizes.

Culvert Length

Metric culverts will be specified in multiples of 0.5 m lengths. Specify the next highest length of culvert required in 0.5 m increments.

Existing English culverts shall be measured to the nearest 0.1 m length.

NOTE: PRODUCT AVAILABILITY SHOULD BE CHECKED WITH THE SUPPLIER PRIOR TO THE PRODUCT BEING SPECIFIED.

UNITS USED ON DRAWINGS

- SI drawings shall use millimeters exclusively, except that elevations and layout dimensions will be called out in meters on the General Layout and Footing Plan Sheets.
- So that it is not necessary to write "mm" after each dimension, each drawing should have the following note on it: "ALL DIMENSIONS ARE MILLIMETERS (mm) UNLESS OTHERWISE NOTED".
- SI drawings should almost never show decimal millimeters (e.g. 2034.5), unless a high precision part or product thickness is being detailed. Use whole millimeters (2035).
- Dual dimensions shall not be used on SI drawings.
- Shop drawings shall be submitted using millimeters only.

Other metric units to be used within the Bureau include:

- The kilogram (kg) is the base unit for mass.
- The newton (N) is the derived unit of force (mass x acceleration = (kgm/s^2)).
- The Pascal (Pa) is the unit of pressure and stress (Pa = N/m^2).
- Structural calculations preferably shall be shown in MPa or kPa.
- Loads preferably shall be specified in kilopascals (kPa).
- Plane angles will continue to be designated in degrees (degrees, minutes, and seconds).

FASTENERS

- Large projects shall use ASTM A325 and A490M metric bolts.
- There are four standard metric bolt sizes, which replace the nine bolts currently used. They are sizes 16, 20, 22, and 24 mm. The 24 mm bolts can be used with the Bridge Engineer's approval.
- Minimum order quantities may apply, so small metric projects should verify availability during design.

MATERIALS

SIEVES

(From Modified AASHTO M92-85 and MDT Materials Manual MT 405)

Sieve Designation, (W)		Nominal Sieve Opening (in.)[C]	Permissible Variation of Average Opening from the Standard Sieve Designation (y)	Intermediate Tolerance (z)[G]	Maximum Individual Opening (x)	Nominal Wire Diameter (mm[A])
Standard[B]	Alternative					
125 mm	5 in.	5	±3.70 mm	130.0 mm	130.9 mm	8.00
106 mm	4.24 in.	4.24	±3.20 mm	110.2 mm	111.1 mm	6.40
100 mm[D]	4 in.[D]	4	±3.00 mm	104.0 mm	104.8 mm	6.30
90 mm	3½ in.	3.5	±2.70 mm	93.6 mm	94.4 mm	6.08
75 mm	3 in.	3	±2.20 mm	78.1 mm	78.7 mm	5.80
63 mm	2½ in.	2.5	±1.90 mm	65.6 mm	66.2 mm	5.50
53 mm	2.12 in.	2.12	±1.60 mm	55.2 mm	55.7 mm	5.15
50 mm[D]	2 in.[D]	2	±1.50 mm	52.1 mm	52.6 mm	5.05
45 mm	1¾ in.	1.75	±1.40 mm	46.9 mm	47.4 mm	4.85
37.5 mm	1½ in.	1.5	±1.10 mm	39.1 mm	39.5 mm	4.59
31.5 mm	1¼ in.	1.25	±1.00 mm	32.9 mm	33.2 mm	4.23
26.5 mm	1.06 in.	1.06	±0.80 mm	27.7 mm	28.0 mm	3.90
25.0 mm[D]	1 in.[D]	1	±0.80 mm	26.1 mm	26.4 mm	3.80
22.4 mm	⅞ in.	0.875	±0.70 mm	23.4 mm	23.7 mm	3.50
19.0 mm	¾ in.	0.750	±0.60 mm	19.9 mm	20.1 mm	3.30
16.0 mm	⅝ in.	0.625	±0.50 mm	16.7 mm	17.0 mm	3.00
13.2 mm	0.530 in.	0.530	±0.41 mm	13.83 mm	14.05 mm	2.75
12.5 mm[D]	½ in.[D]	0.500	±0.39 mm	13.10 mm	13.31 mm	2.67
11.2 mm	7/16 in.	0.438	±0.35 mm	11.75 mm	11.94 mm	2.45
9.50 mm	⅜ in.	0.375	±0.30 mm	9.97 mm	10.16 mm	2.27
8.00 mm	5/16 in.	0.312	±0.25 mm	8.41 mm	8.58 mm	2.07
6.70 mm	0.265 in.	0.265	±0.21 mm	7.05 mm	7.20 mm	1.87
6.30 mm[D]	¼ in.[D]	0.250	±0.20 mm	6.64 mm	6.78 mm	1.82
5.60 mm	No. 3½[E]	0.223	±0.18 mm	5.90 mm	6.04 mm	1.68
4.75 mm	No. 4	0.187	±0.15 mm	5.02 mm	5.14 mm	1.54
4.00 mm	No. 5	0.157	±0.13 mm	4.23 mm	4.35 mm	1.37
3.35 mm	No. 6	0.132	±0.11 mm	3.55 mm	3.66 mm	1.23
2.80 mm	No. 7	0.111	±0.095 mm	2.975 mm	3.070 mm	1.10

[A] The average diameter of the warp and of the shoot wires, taken separately, of the cloth of any sieve shall not deviate from the nominal values by more than the following:
Sieves coarser than 600 μm → 5% Sieves 600 to 125 μm → 7½% Sieves finer than 125 μm → 10%

[B] These standard designations correspond to the values for test sieve apertures recommended by the International Standards Organization, Geneva, Switzerland.

[C] Only approximately equivalent to the metric values in Column 1.

[D] These sieves are not in the standard series, but they have been included because they are in common usage.

[E] These numbers (3½ to 635) are the approximate number of openings per linear in., but it is preferred that the sieve be identified by the standard designation in mm or μm.

[F] 1000 μm = 1 mm.

[G] Not more than 5% of the openings may fall between the limits set by the values in Column 5 and Column 6.

SIEVES (Cont.)

Sieve Designation, (W)		Nominal Sieve Opening (in.)[C]	Permissible Variation of Average Opening from the Standard Sieve Designation (y)	Intermediate Tolerance (z)[C]	Maximum Individual Opening (x)	Nominal Wire Diameter (mm[A])
Standard[B]	Alternative					
2.36 mm	No. 8	0.093 7	±0.080 mm	2.515 mm	2.600 mm	1.00
2.00 mm	No. 10	0.078 7	±0.070 mm	2.135 mm	2.215 mm	0.900
1.70 mm	No. 12[E]	0.066 1	±0.060 mm	1.820 mm	1.890 mm	0.810
1.40 mm	No. 14	0.055 5	±0.050 mm	1.505 mm	1.565 mm	0.725
1.18 mm	No. 16	0.046 9	±0.045 mm	1.270 mm	1.330 mm	0.650
1.00 mm	No. 18	0.039 4	±0.040 mm	1.080 mm	1.135 mm	0.580
850 μm[F]	No. 20	0.033 1	±35 μm	925 μm	970 μm	0.510
710 μm	No. 25	0.027 8	±30 μm	775 μm	815 μm	0.450
600 μm	No. 30	0.023 4	±25 μm	660 μm	695 μm	0.390
500 μm	No. 35	0.019 7	±20 μm	550 μm	585 μm	0.340
425 μm	No. 40	0.016 5	±19 μm	471 μm	502 μm	0.290
355 μm	No. 45	0.013 9	±16 μm	396 μm	425 μm	0.247
300 μm	No. 50	0.011 7	±14 μm	337 μm	363 μm	0.215
250 μm	No. 60	0.009 8	±12 μm	283 μm	306 μm	0.180
212 μm	No. 70	0.008 3	±10 μm	242 μm	263 μm	0.152
180 μm	No. 80	0.007 0	±9 μm	207 μm	227 μm	0.131
150 μm	No. 100	0.005 9	±8 μm	174 μm	192 μm	0.110
125 μm	No. 120	0.004 9	±7 μm	147 μm	163 μm	0.091
106 μm	No. 140	0.004 1	±6 μm	126 μm	141 μm	0.076
90 μm	No. 170	0.003 5	±5 μm	108 μm	122 μm	0.064
75 μm	No. 200	0.002 9	±5 μm	91 μm	103 μm	0.053
63 μm	No. 230	0.002 5	±4 μm	77 μm	89 μm	0.044
53 μm	No. 270	0.002 1	±4 μm	66 μm	76 μm	0.037
45 μm	No. 325	0.001 7	±3 μm	57 μm	66 μm	0.030
38 μm	No. 400	0.001 5	±3 μm	48 μm	57 μm	0.025
32 μm	No. 450	0.001 2	±3 μm	42 μm	50 μm	0.028
25 μm[D]	No. 500	0.001 0	±3 μm	34 μm	41 μm	0.025
20 μm[D]	No. 635	0.000 8	±3 μm	29 μm	35 μm	0.020

[A] The average diameter of the warp and of the shoot wires, taken separately, of the cloth of any sieve shall not deviate from the nominal values by more than the following: Sieves coarser than 600 μm → 5 % Sieves 600 to 125 μm → 7½ % Sieves finer than 125 μm → 10 %

[B] These standard designations correspond to the values for test sieve apertures recommended by the International Standards Organization, Geneva, Switzerland.

[C] Only approximately equivalent to the metric values in Column 1.

[D] These sieves are not in the standard series, but they have been included because they are in common usage.

[E] These numbers (3½ to 635) are the approximate number of openings per linear in., but it is preferred that the sieve be identified by the standard designation in mm or μm.

[F] 1000 μm = 1 mm.

[G] Not more than 5 % of the openings may fall between the limits set by the values in Column 5 and Column 6.

TRAFFIC

SIGN CONVERSION VALUES

This list will not be exhaustive, but the principles set out should allow conversion of any value encountered.

Dimension in inches x 25 = millimeters

Typical metric sign sizes
- 300 mm
- 450 mm
- 600 mm
- 750 mm
- 900 mm
- 1050 mm
- 1200 mm
- 1350 mm
- 1500 mm

The difference between a hard conversion (1 inch = 25 mm) and a soft conversion (1 inch = 25.4 mm) is only 1.6 percent.

SPEED LIMIT SIGNS

The following conversion table will indicate what the Department will use in converting Miles Per Hour to Kilometers Per Hour:

25 MPH	-	40 km/h
30 MPH	-	50 km/h
35 MPH	-	60 km/h
40 MPH	-	60 km/h
45 MPH	-	70 km/h
50 MPH	-	80 km/h
55 MPH	-	90 km/h *
65 MPH	-	110 km/h *

* Consistent with Federal and State Laws

All of the conversions are in 10 km/h increments and for the most part each of the conversions from MPH to km/h are straight across the board. The only minor differences are with the conversion of 35 mph and 40 mph. They will both go to 60 km/h. Sixty km/h is equal to 37.5 MPH. All new special speed zones will follow existing development procedures. Speed limits will be displayed in 10 km/h increments.

IMPACTS TO THE MDT DESIGN PROCESS

ENVIRONMENTAL

All reports are required in metric units as of March, 1994.

USER SERVICES

Computer programs will have to be rewritten or appropriate metric conversion factors need to be incorporated into the programs.

DATA PROCESSING

New paper sizes will be used in the future when manufacturer's begin producing the metric sizes.

Metric writing rules will need to be incorporated into documents being produced.

PHOTOGRAMMETRY AND SURVEY

COORDINATES

One exception to the exclusive use of the SI Foot (1 foot = 0.304 8 m) is some coordinate data received from the Photogrammetry and Survey Section. The electronic survey equipment used by the MDT measures distances in meters and then internally converts the distance to feet using the U.S. Survey Foot (1 foot = 0.304 800 61 m) which is slightly different than the SI Foot.

For all practical purposes, the two are the same with approximately two parts per million difference. Where this causes a problem is when metric coordinates are developed using English survey data.

The Photogrammetry and Survey Section will identify the conversion factor used to produce metric coordinates. The designer shall identify the conversion factor used as a footnote to the coordinate table in the plans.

Stationing, bearing, and section tie calculations using metric coordinates will need to be performed using the appropriate conversion factor. If there is any question as to the appropriate conversion factor, contact the Photogrammetry and Survey Section.

APPLICATIONS FOR MDT SURVEYS

Distance measurements for control work will now be recorded to the third decimal place. This is consistent with the output from EDM's. Some chains can be directly read to the third decimal place of a meter, while others will require estimation for the third place. Less precise measurements, typically measurements recorded to the nearest tenth of a foot, will be recorded to the nearest hundredth of a meter.

IMPACTS TO THE MDT

CONSTRUCTION

Plans, bid packages, and contract administration will be required to be carried out in metric units.

The historical database (average bid prices) will need to be converted to metric units for cost estimating purposes.

Inspection will be carried out in metric units when the new spec book is published in 1995.

MAINTENANCE

Metric units will be used for all product purchases such as fuels, paints, salt, and gravel.

The Maintenance Management System (MMS) will have to be cross referenced to kilometer posts in the future.

PUBLIC AFFAIRS

The Public Affairs Unit will be responsible for alerting the driving public to the metric changes through public announcements and informational news releases.

METRIC SOLUTIONS TO PROBLEMS

GENERAL

METRIC SOLUTIONS TO PROBLEMS

USER SERVICES

DATA PROCESSING

METRIC SOLUTIONS TO DESIGN PROBLEMS

RIGHT OF WAY

ROAD DESIGN

METRIC SOLUTIONS TO DESIGN PROBLEMS

ROAD DESIGN

HYDRAULICS

METRIC SOLUTIONS TO DESIGN PROBLEMS.

BRIDGE DESIGN

MATERIALS

METRIC SOLUTIONS TO DESIGN PROBLEMS-

TRAFFIC DESIGN

ENVIRONMENTAL

METRIC SOLUTIONS TO DESIGN PROBLEMS

PHOTOGRAMMETRY AND SURVEY

METRIC SOLUTIONS TO PROBLEMS

CONSTRUCTION

METRIC SOLUTIONS TO PROBLEMS

MAINTENANCE